A Combination of the FDTD Method and Signal Processing Techniques: Fast FDTD/ARMA Approach

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The finite difference time domain (FDTD) method is a powerful and versatile numerical tool to analyze various electromagnetic structures. It has been widely used in the guided waves, radiation, and scattering analyses. The electromagnetic fields are calculated in the time domain using the Yee's algorithm and the frequency domain properties of the analyzed structure can be readily obtained through the Fourier transform. However, a relatively long time sequence needs to be computed for accurate characterizations of complex structures.

Traditional fast algorithms. The traditional fast algorithms start with a general complex exponential model for the FDTD time domain data as below:

$$h(n) = \sum_{k=1}^{K} C_k e^{(-\alpha_k + j2\pi f_k) dt \cdot n} \qquad n = 1, 2, \cdots N \tag{1}$$

The coefficients can be determined by the Prony method or the generalized pencil-of-function method.

Novel FDTD/ARMA approach. From the signal processing viewpoint, the time domain data of the FDTD simulation can be defined as an impulse response (IR) of a linear time invariance system with an autoregressive moving average (ARMA) transfer function (A. K. Shaw and K. Naishadham, *IEEE Trans. Antennas Propagat.*, 49(3), 327-339, 2001):

$$H(z) = \frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2} + \cdots + a_q Z^{-q}}{1 + b_1 Z^{-1} + b_2 Z^{-2} + \cdots + b_p Z^{-p}} \tag{2}$$

It is noticed that if one takes *z* transform on both side of (1):

$$H(z) = \sum_{k=1}^{K} \frac{C_k}{(1 - (-\alpha_k + j2\pi f_k) \cdot Z^{-1})} = \frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2} + \cdots + a_{p-1} Z^{-(p-1)}}{1 + b_1 Z^{-1} + b_2 Z^{-2} + \cdots + b_p Z^{-p}} \tag{3}$$

Thus, Eq. (1) is a special case of Eq. (2) when $q = p-1$. The coefficients of Eq. (2) can be determined through an iterative optimization process.

Antenna analysis using the FDTD/ARMA method. Several microstrip antennas are analyzed using both the FDTD/ARMA method and the traditional FDTD/Prony method. It is observed that the error of the ARMA model is smaller than that of the Prony method. Additionally, for a given error criterion the order of the ARMA model appears to be much smaller than that required by the Prony method.